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EXPERIMENTAL EVOLUTION

Regeneration in Lumbriculus.[1]—In the August number of Roux's *Archiv* a paper by Conrad Müller describes regeneration in *Lumbriculus variegatus* and *Tubifex rivulorum.* The paper of 70 pages contains 24 figures and 14 full-page tables. Despite its bulk one can not help being impressed with its failure to contribute much that is new to our present knowledge of regeneration in Lumbriculus.

Müller's chief concern seems to be the extent of the power of regeneration. He first studied the power to regenerate a head or a tail in Lumbriculus, and from a great many experiments, very elaborately described, he found that new heads may regenerate 17–22 times in succession, while new tails regenerate 33–42 times after successive operations. From these facts he draws the general conclusion that the power of posterior regeneration is twice as great as the power of anterior regeneration. Bonnet in 1741, in his classical investigation of the regeneration in Lumbriculus, found also that heads and tails regenerate several times after successive operations—only Bonnet never obtained regeneration so many times.

These results of Müller may be, however, interpreted otherwise than that the power of posterior regeneration is greater than the power of anterior regeneration, since the worms regenerating tails had heads and could therefore feed, while the worms regenerating heads could not feed.

Regarding the relation between length of time during which a tail regenerates and the number of segments that are produced Müller sets up the following "law"—"The number of segments newly formed stands in direct relation to the length of time of regeneration; i. e., during equal periods of time there are regenerated posteriorly equal numbers of segments." He also investigated the number of posterior segments that regenerate after successive operations performed at regular intervals. In the course of ten months he cut off the regenerating tails 22 times (every 14 days) and found that in this case also "after repeated removals of a regenerating tail the same number of new segments is formed during similar periods of time." He then refers to my work on regeneration in Lumbriculus and says that, "Bei dem von Morgulis und mir behandelten Object scheint

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[1] *Arch. f. Entwicklungs u. d. Organismen,* XXVI, 1908.

dass kein Unterscheid zu machen.'' But this ''agreement'' is due apparently to a misunderstanding. On the contrary, I got the opposite result in my studies on regeneration in Lumbriculus. I found that the number of segments formed within equal lengths of time decreases the more the time that has elapsed since the operation was performed. Concerning the rate of regeneration for similar periods of time (but after successive operations) my statement is so simple that it is surprising that it should have been misinterpreted. I said—'' . . . in the course of the second period of two weeks the pieces regenerate about one half as many segments as when regenerating for the first period of two weeks.'' After a third period of two weeks ''the pieces have regenerated only about one half as many segments regenerated for the second period of two weeks, and about one fourth as many as for the first two weeks.''[2]

Müller quotes my general conclusion, based upon these facts, that ''a piece of worm, when subjected to the operation of cutting a few times will produce more new tissue for the same length of time than when subjected to cutting only once,'' and says: ''Desartiges habe ich ebenfalls beobachted.''! But unless I misunderstood Müller's point, his ''law'' is the reverse of my conclusion. He says that a worm regenerates on an average 25 segments in 14 days; after the following 14 days it will have regenerated 50 segments, or 25 segments more, etc., so that the number of regenerating segments is in direct proportion to the length of time. His tables show also that when the tails have been cut off every 14 days 25 new segments regenerate each time. In other words, a worm left to regenerate for 8 weeks should regenerate 100 segments (25 segments every 2 weeks), while another worm in which the tail is removed at the end of every 14 days regenerates 25 segments after each successive operation, and, therefore, will also have formed 100 segments at the close of 8 weeks.

So that a worm that had been operated upon 4 times regenerates 100 segments in the same time in which another worm, that had been operated upon only once, also regenerates 100 segments. This certainly does not uphold my contention; it is also evident that Müller's ''law'' is incompatible with my conclusion cited above, yet he seems to find them both to be true. Müller speaks at great length of the regeneration of pieces of

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[2] *Jour. Exp. Zool.*, IV, 1907, pp. 561 and 562.

Lumbriculus without adding anything new. His discovery that single segments are capable of anterior as well as posterior regeneration is not new, since I have shown in my paper, published ten months earlier, that single segments regenerate in this way. Although Müller reviews my experiments with single segments in full detail, he feels dubious as to whether I really did have single segments regenerating. The scepticism is due to the fact that, according to my description, the worms have been regenerating in clean water, and in Müller's experience "war das Halten der Tiere in reinem Wasser einfach ausgeschlossen." I may therefore mention in this place that pieces of Lumbriculus have been reared in clean water even by Bonnet, and that for the three years that I have been studying regeneration in Lumbriculus the worms were and are now *invariably* kept in clean water.

In the chapter dealing with the regeneration of regenerated pieces Müller makes no mention of my experiments, which in fact were the first experiments of that nature in Lumbriculus. He states that he got the regenerated tail, when detached from the parent body, to regenerate new heads or tails 23 times.

The fact that Lumbriculus can regenerate its head 23 times and its tail 42 times in succession is of considerable theoretical importance, and even more so is the statement that regenerated pieces are also capable of regenerating heads and tails many times in succession. It seems to me that these facts bear directly on the hypothesis of formative substances. If such substances are connected with the regeneration of a head or a tail it would be hard to conceive how such an enormous quantity of head- and tail-forming substances has become stored up in the cells to insure the possibility of regeneration after 23–42 operations, unless a further assumption is made that those substances themselves are capable of reproduction. Still harder would it be to conceive how a regenerated tail, the supposed product of tail-forming substances, has become stored up with such an abundance of reserve formative substances as to be able to produce heads or tails time after time. To make such a demand on our credulity would be asking a great deal.

Müller's work on Tubifex is practically a repetition of his work on Lumbriculus. There he finds that a head regenerates only when 4–6 anterior segments are removed, and does not regenerate more than 7 times in succession, while a tail may regenerate even 40 times. The successive regeneration of heads may be checked by the regeneration of the tail. Regenerated parts when detached from the worm are not capable of new regeneration.

The most novel part of the paper is that which describes various cases of heteromorphosis, and other malformations in the regenerating tail, including the regeneration of double tails in Lumbriculus or of triple tails in Tubifex.

Sergius Morgulis.

September 7, 1908.

THE BUDGETT MEMORIAL VOLUME

John Samuel Budgett, naturalist, explorer, scholar and artist, was born in Bristol, England, in 1872. He received his education at University College in Bristol, and later at the University of Cambridge, where he received the appointment as Balfour Student in Natural Sciences, "the zoological blue ribbon of Cambridge." Here he gave, in 1902, a course of lectures on on the "Geographical Distribution of Animals," succeeding in this work the eminent ornithologist, Professor Alfred Newton. His work at Cambridge was interrupted and enriched by zoological exploring expeditions to South America and to Africa, efforts which from the natural history side were successful in the highest degree, but which ultimately cost him his life.

The first of these, in 1896, was to the Swamps of La Plata River at Gran Chaco in Paraguay, in search of the singular mud-fish, *Lepidosiren paradoxa.* The life history and embryology of this fish was expected to throw much light on the nature of the order of Dipnoans to which it belongs. All stages of the life history of *Lepidosiren* were represented in the collection made by Mr. Budgett, and the expedition was brilliantly successful.

On the next expedition, in 1899, he visited the Gambia River, where another genus, Protopterus, of the same group of mudfishes is found.

In the third expedition, in 1900, he visited the Gambia again, gathering material for not only the life history of the dipnoan, Protopterus, but of different species of the equally interesting

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[1] The work of John Samuel Budgett, Balfour Student at the University of Cambridge, edited by J. Graham Kerr, University Press, Cambridge, G. P. Putnam Sons, New York, p. 422 quarto, with many engravings in stone. Price $7.00.